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# A Planetary Protection Strategy for the Mars Aerial Regional-Scale Environmental Survey (*ARES*) Mission Concept

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National Aeronautics and  
Space Administration

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# TABLE OF CONTENTS

<b>1.0</b>	<b>Introduction.....</b>	<b>3</b>
<b>2.0</b>	<b>ARES Mission Description.....</b>	<b>4</b>
2.1	Concept of Operations .....	4
2.2	Target Region.....	5
2.3	Science Objectives and Measurement Objectives .....	6
2.4	Mission Classification.....	7
<b>3.0</b>	<b>Non-Impacting Spaceflight Hardware (Category III).....</b>	<b>9</b>
3.1.1	Third Stage of Launch Vehicle .....	9
3.1.2	Carrier Spacecraft .....	9
3.1.3	Orbital Lifetime and Probability of Impact .....	9
<b>4.0</b>	<b>Mars Impacting Hardware (Category IVa) .....</b>	<b>11</b>
4.1	Estimating Biological Contamination.....	11
4.1.1	Clean Room Assembly Requirement.....	11
4.1.2	Spacecraft Microbial Limits .....	11
4.1.3	Specifications for Bioburden Estimation .....	12
4.1.4	Microbial Reduction Parameters.....	13
4.2	ARES Bioburden Allocation.....	14
4.2.1	Entry, Descent, and Deployment System .....	14
4.2.2	Atmospheric Flight System.....	17
4.2.3	ARES Contamination Analysis (Category IVa) .....	18
4.2.4	Hardware Microbial Reduction Strategy .....	19
4.2.5	ARES Bioburden Allocation.....	20
<b>5.0</b>	<b>Verifying Microbial Burden Allocations .....</b>	<b>25</b>
5.1.1	Sampling Plan .....	25
5.1.2	Final Bioburden Determination .....	26
5.1.3	Total Bioburden .....	26
<b>6.0</b>	<b>Preventing Recontamination.....</b>	<b>27</b>
6.1.1	Hardware Assembly and Integration .....	27
6.1.2	Launch and Cruise Operations.....	27
<b>7.0</b>	<b>Organization and Responsibility .....</b>	<b>28</b>
7.1	Biological Contamination Control.....	28
7.2	Microbiological Management and Operations.....	28
<b>8.0</b>	<b>Planetary Protection Design and Analysis Planned Activities.....</b>	<b>29</b>
<b>9.0</b>	<b>Planetary Protection Documentation.....</b>	<b>31</b>
9.1	Planetary Protection Implementation Document .....	31
9.2	Pre-Launch Report .....	31
9.3	Post-Launch Report .....	31
9.4	End-of-Mission Report .....	31
9.5	Documentation Schedule .....	32
<b>10.0</b>	<b>Reviews.....</b>	<b>33</b>
10.1	Project Planetary Protection Review .....	33
10.2	Planetary Protection Compliance Status Reviews .....	33
10.3	Pre-Launch Planetary Protection Review .....	33
<b>11.0</b>	<b>Facilities and Services.....</b>	<b>34</b>
11.1	ARES Microbiology Laboratory (JPL).....	34

11.2	ARES Microbiology Laboratory (LaRC) .....	34
11.3	ARES Microbiology Laboratory (KSC) .....	34
11.4	Government Services .....	34
<b>12.0</b>	<b>Acknowledgements .....</b>	<b>35</b>
<b>13.0</b>	<b>References.....</b>	<b>35</b>
<b>14.0</b>	<b>List of Acronyms .....</b>	<b>36</b>

## TABLE OF FIGURES

Figure 1.	ARES Mission Concept Overview .....	4
Figure 2.	Target Region. ....	5
Figure 3.	Spaceflight Hardware. ....	8
Figure 4.	Carrier Spacecraft Hardware. ....	9
Figure 5.	ARES Aeroshell .....	15
Figure 6.	Disk Gap Band (DGB) Entry Parachute.....	15
Figure 7.	EDD Drogue Chute .....	15
Figure 8.	AFS Extraction System .....	16
Figure 9.	Subsystems of the ARES Atmospheric Flight System.....	17

## TABLE OF TABLES

Table 1.	Planetary Protection Mission Categories.....	7
Table 2.	Subcategories for Mars Landers .....	7
Table 3.	Mission Catagories .....	8
Table 4.	Specifications for Surface Microbial Density.....	12
Table 5.	Specifications for Encapsulated and Enclosed Microbial Density .....	13
Table 6.	Standard D-values for Dry Heat Microbial Reduction .....	13
Table 7.	ARES Hardware Microbial Reduction Strategy.....	19
Table 8.	Atmospheric Flight System (AFS) Microbial Burden Analysis.....	21
Table 9.	ARES Bioburden Allocation .....	24
Table 10.	Example Summary Bioassay Schedule.....	25
Table 11.	Continued Planetary Protection Activities.....	30
Table 12.	Planetary Protection Document Schedule.....	32
Table 13.	Formal Planetary Protection Review Schedule .....	33

## 1.0 INTRODUCTION

The Committee for Space Research (COSPAR)<sup>1</sup> maintains the policy of planetary protection established in the UN Space Treaty of 1967 which states:

*States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of Earth resulting from the introduction of extraterrestrial matter, and where necessary, shall adopt appropriate measures for this purpose.*  
(UN 1967)

The purpose of Planetary Protection is to ensure that scientific investigations of possible life forms on other planetary bodies are not jeopardized by contamination caused by earth-based organisms. In addition, the Earth must be protected from potential hazards being returned from space, another planet, or other extraterrestrial sources. To ensure planetary protection, NASA has adopted a policy directive, NPD 8020.7F “Biological Contamination Control for Outbound and Inbound Planetary Spacecraft” [1], which applies to all space flight missions which may intentionally or inadvertently carry Earth organisms to other planets or return organisms from extraterrestrial sources back into the Earth’s biosphere.

Specific constraints on spaceflight missions are dependant on the type of mission, target planet or body, and current knowledge base of the target body. Typical constraints involve reducing biological contamination on spacecraft, restrictions on landings sites or impact points, and inventories of organic constituents. These constraints are outlined in NASA Procedural Requirements NPR 8020.12C “Planetary Protection Provisions for Robotic Extraterrestrial Mission” [2].

The Aerial Regional-scale Environmental Survey (ARES) is a Mars exploration mission concept designed to send an airplane to fly through the lower atmosphere of Mars, with the goal of taking scientific measurements of the atmosphere, surface, and subsurface phenomenon. ARES was first proposed to the Mars Scout program in December 2002 for a 2007 launch opportunity and was selected to proceed with a Phase A study, step-2 proposal which was submitted in May 2003. ARES was not selected for the Scout mission, but efforts continued on risk reduction of the atmospheric flight system in preparation for the next Mars Scout opportunity in 2006. The ARES concept was again proposed in July 2006 to the Mars Scout program but was not selected to proceed into Phase A. This document describes the Planetary Protection strategy that was developed in ARES Pre Phase-A [3] activities to help identify, early in the design process, certain hardware, assemblies, and/or subsystems that will require unique design considerations based on constraints imposed by Planetary Protection requirements. Had ARES been selected as an exploration project, information in this document would make up the ARES Project Planetary Protection Plan.

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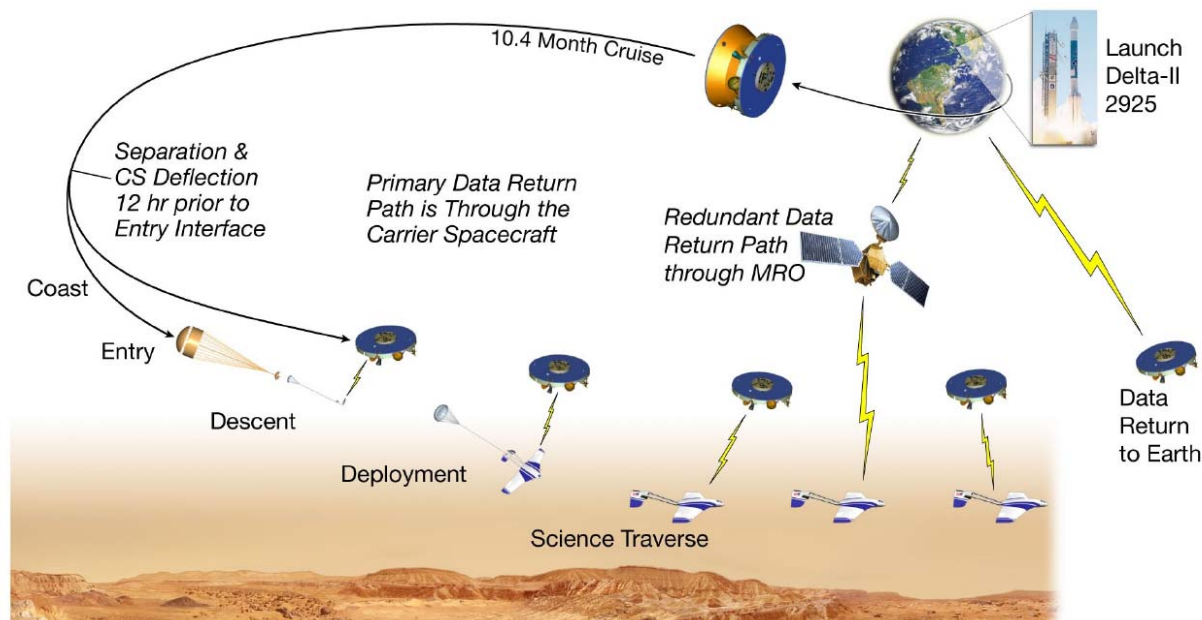
<sup>1</sup> COSPAR was established by the International Council of Scientific Unions (ICSU) during an international meeting in 1958 following the launch of earth’s first satellite in 1957 by USSR.

## 2.0 ARES MISSION DESCRIPTION

The Aerial Regional-scale Environmental Survey (ARES) mission expands upon other Mars exploration missions, including Viking, Mars Global Surveyor (MGS), Odyssey, and the Mars Exploration Rovers (MER), to examine the structure and evolution of Mars' atmosphere, surface, and interior. The ARES atmospheric flight system will fly above the Southern Highlands to study crustal magnetism, atmospheric boundary layer composition, chemistry and dynamics, and also to explore for near-surface water.

### 2.1 CONCEPT OF OPERATIONS

ARES will launch from Kennedy Space Center in October, 2011 on a Delta II 2925, placing it on a 10-month trajectory to Mars. ARES will utilize a Type II interplanetary trajectory with a series of five planned trajectory correction maneuvers (TCMs) with a final direct entry into Mars. The entry system (aeroshell and atmospheric flight system) will separate from the carrier spacecraft before entering Mars atmosphere. The carrier spacecraft will perform a divert maneuver to a Mars flyby trajectory, enabling it to relay to Earth the science and engineering data that will be collected during the airplane flight. Mars Reconnaissance Orbiter (MRO) will serve as a redundant data return path for critical data. An overview of the mission concept is shown in Figure 1.



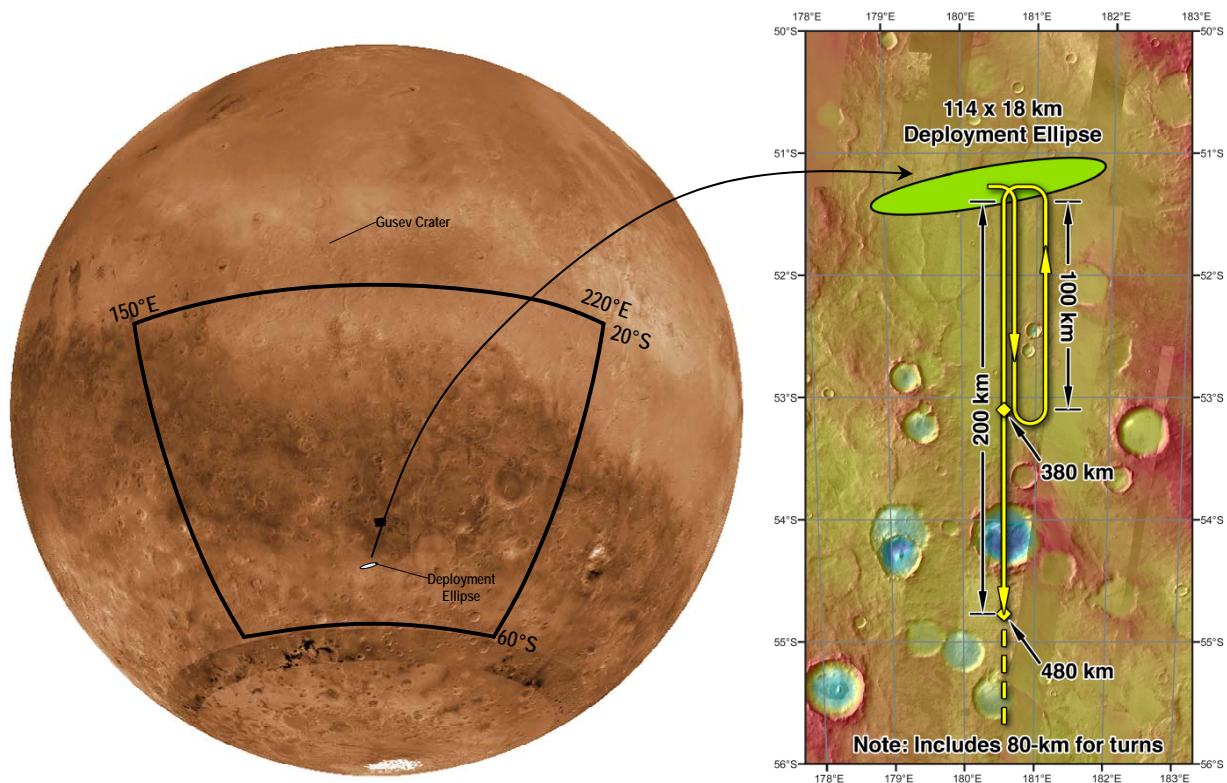
**Figure 1. ARES Mission Concept Overview**



## 2.2 TARGET REGION

The ARES Science Target Area (STA) is an optimal region selected by the science team to assess the science objectives listed in Section 2.3. The STA is defined by the intersection of the Mars crustal magnetism and water initiated atmospheric chemistry regions of interest. The areas of strongest magnetization are between 20° and 90° S latitude and 150° and 210° E longitude, exhibiting linear East-West features with alternating polarity that extend more than 2000 km. The combination of these two zones yields a large STA spanning 20° to 60° S latitude and 150° to 210° E longitude (See Figure 2). This STA region contains an abundance of potential investigation areas that allow individual science objectives to be placed in a cohesive regional and epochal context.

During a science flight traverse of more than 55 minutes, the ARES rocket-propelled airplane will fly over 480 km obtaining measurements of crustal magnetism and the atmosphere. The reference traverse begins at a nominal delivery location of (51.2° S, 180.0° E) and travels >1.7° south prior to performing an aeromagnetic survey defined by two additional parallel North-South tracks, each of length 100 km, shown in Figure 2. Data is relayed to the fly-by spacecraft and by a redundant path to the MRO orbiter. At the end of the traverse, the airplane makes a non-nominal impact on the surface at which point the data link is assumed to be lost and the data collection portion of the mission is complete.



**Figure 2. Target Region.**  
-20° to -60° Latitude, 180° Long (+/- 30°)

### 2.3 SCIENCE OBJECTIVES AND MEASUREMENT OBJECTIVES

ARES expands upon Viking, Mars Global Surveyor (MGS), Odyssey, Mars Express and MER discoveries, providing a window into the structure and evolution of Mars' atmosphere, surface, and interior. ARES' Crustal Magnetism, Boundary Layer Chemistry and Dynamics, and Near-Surface Water goals embody the fundamental science measurement objectives below. Note that ARES does not contain on-board instruments for investigating extant martian life, a key characteristics in determining the mission classification.

1. ARES will enable an improved understanding of the detailed nature of crustal magnetism on Mars and modeling of Mars crustal evolution, tectonic history and the chronology of the dynamo. ARES will take continuous regional-scale (>200-km, 3.4 deg latitude) crustal magnetic field intensity measurements at 2-km spatial resolution to determine the regional-scale (>100-km, 1.7 deg latitude) crustal magnetic field source structure.
2. ARES will study the near-surface atmospheric composition, chemistry and dynamic behavior, and the chemical coupling between the surface and atmosphere. ARES will measure the regional-scale (>100-km, 1.7 deg latitude) spatial variability of water vapor concentration, and the spatial variability and concentration of biogenic gases: i.e., methane (CH<sub>4</sub>), ammonia (NH<sub>3</sub>), ethane (C<sub>2</sub>H<sub>6</sub>); volcanic gases: i.e., sulfur dioxide (SO<sub>2</sub>), and hydrogen sulfide (H<sub>2</sub>S); and chemically active gases: i.e., hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), ozone (O<sub>3</sub>), hydroxyl (OH), formaldehyde (H<sub>2</sub>CO). ARES will also determine the regional scale spatial variability of planetary boundary layer parameters (temperature, pressure, density, wind speed, wind direction).
3. ARES will examine water-equivalent hydrogen abundance and its relationship to inferred near-surface water and hydrated minerals. ARES will measure the regional-scale (>100-km, 1.7 deg latitude) spatial variability (2-km resolution), depth and concentration of near-surface water-equivalent hydrogen. Resolve sub-surface water features <2-km diameter.
4. ARES will determine the planetary entry parameters (temperature, pressure, density, wind speed, and wind direction) at 50 Hz sample rate.

## 2.4 MISSION CLASSIFICATION

Planetary missions fall into one (or more) of five categories based on the type of mission, planetary target, and specific regions within that target to be explored. Missions are based on the scientific interest of the target, relative to chemical evolution or the origin of life, and the chance of jeopardizing future biological experiments through earth-based contaminants. Planetary Protection categories are shown below in Table 1.

**Table 1. Planetary Protection Mission Categories**

Interest Relative to Chemical Evolution and Origin of Life	Chance for Contamination to Jeopardize Future Biological Experiments	Mission Type	Planetary Protection Mission Category
Minimal	None	Any	I
Significant	Remote	Any	II
Significant	Significant	Flyby, Orbiter	III
Significant	Significant	Lander, Probe	IV
-	-	All Earth Return	V

For Mars landers or probes, Category IV is divided into three subcategories, IVa, IVb, IVc, depending on the type of instrumentation carried and whether a Martian “Special Region” is to be explored (See Table 2).

*A Special Region is defined as a region within which terrestrial organisms are likely to propagate OR a region which is interpreted to have a high potential for the existence of extant Martian life forms. Given current understanding, this applies to regions where liquid water is present or may occur [2].*

**Table 2. Subcategories for Mars Landers**

On-board Instruments for Investigation of Extant Martian Life	Investigating Martian “Special Regions”	Planetary Protection Mission Category
NO	NO	IVa
YES	NO	IVb
YES	YES	IVc
NO	YES	IVc

Additionally, the MEPAG Special Regions Science Analysis Group has determined that a potential exists for Spacecraft Induced Special Regions.

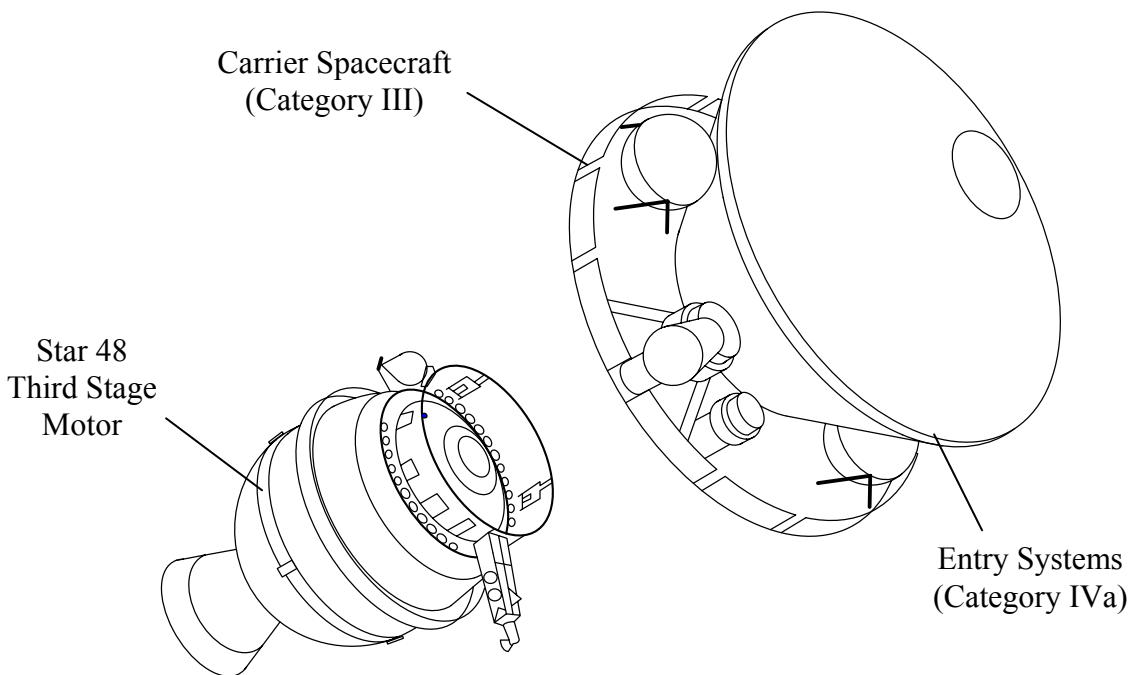
*It is possible for spacecraft to induce conditions that could exceed for some time the threshold conditions for biological propagation, even when the ambient conditions were in equilibrium before the spacecraft arrived. Whether a special region is induced or not depends on the configuration of the spacecraft, where it is sent, and what it does. This possibility is best evaluated on a case-by-case basis [4].*

For the ARES mission, the hardware was split into two categories; impacting hardware, or that which will enter the atmosphere of Mars and impact the surface, and non-impacting hardware, or that which is intended for fly-by and miss the planet. The mission flight hardware consists of a carrier spacecraft (CS), an Entry, Descent, and Deployment (EDD) system, and an Atmospheric Flight System (AFS). Previous communications with the NASA Planetary Protection Officer (PPO) for ARES’ two diverse flight system elements led to the provisional categories shown in Table 3.

**Table 3. Mission Catagories**

System	PP Category
Carrier Spacecraft	Category III
Airplane with Science Payload	Category IVa
Entry, Descent, Deployment	Category IVa

Category III is judged appropriate for the CS since it is a flyby mission. A Category IVa rating governs the AFS and EDD elements, since 1) these elements are considered Mars probes without life detection experiments and 2) regions defined as special interest to life detection will be avoided by the ARES mission. Regions where there is abundant ground ice but no evidence for liquid water (such as our current science target area described in Section 1.1), would not be considered special for ARES due to the thermal environment of this area. Heat sources on ARES (either the EDD elements or the AFS) are due to residual heat within the systems and components. As with the surface missions, the component temperatures are in excess of 5°C therefore an analysis of the potential for the mission elements to create a spacecraft induced region will be performed in Phase B. The ARES flight path latitude range covers a wide range of geologic terrains with highly variable water ice content. The ARES team will work with NASA's PPO to ensure ARES avoids any region deemed special.



**Figure 3. Spaceflight Hardware.**

*Third Stage Star-48 Motor, Carrier Spacecraft, and Entry System are all subject to Planetary Protection requirements [5].*

### 3.0 NON-IMPACTING SPACEFLIGHT HARDWARE (CATEGORY III)

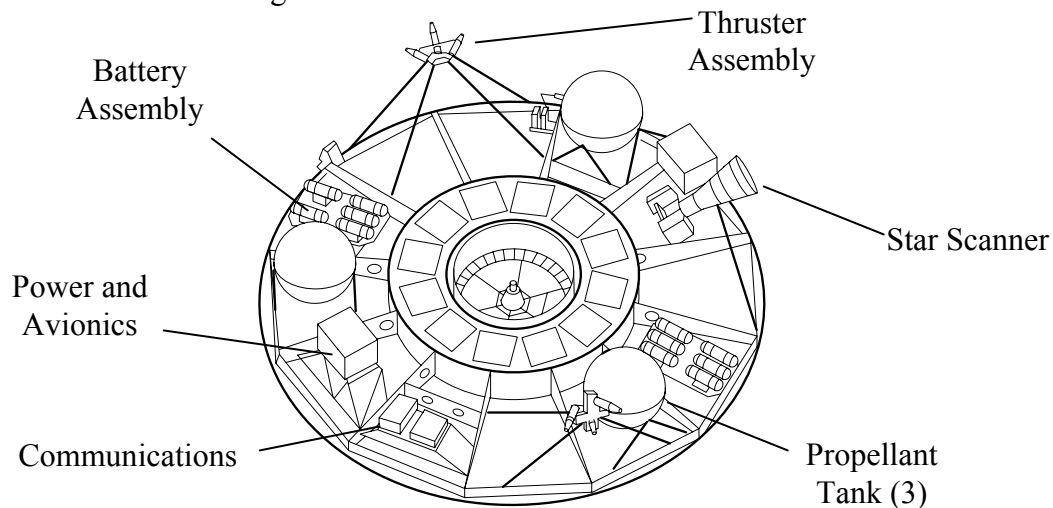
Spaceflight hardware which is subjected to Planetary Protection constraints consists of only such hardware that leaves Earth's orbit on an interplanetary trajectory. The Delta II SRMs, first and second stages of the launch vehicle, and the launch vehicle fairing fall back to Earth or burn-up in Earth's atmosphere. The remaining hardware are addressed below.

#### 3.1.1 Third Stage of Launch Vehicle

The third stage, Star-48 motor was developed by Thiokol Propulsion and now manufactured by The Boeing Company (See Figure 3). The Star-48 is a solid rocket motor which produces about 57.2 kN of thrust with a fuel casing diameter of 48 inches and can carry approximately 2000 kg of propellant. This motor is used to place the spacecraft and entry systems into an interplanetary trajectory towards Mars. At approximately 30 minutes after launch, the Star-48 third stage begins its burn. An aim point bias is used to prevent the third-stage from achieving an impact trajectory to Mars. The third stage separates shortly following burnout. The aim point bias for the carrier spacecraft and entry system is removed through a series of trajectory correction maneuvers later performed by the carrier spacecraft.

#### 3.1.2 Carrier Spacecraft

The ARES Carrier Spacecraft (CS) utilizes an MER build to print primary structure and GN&C subsystems, along with the JPL institutionally developed MSAP C&DH, FSW and Power subsystems. A diagram of the CS is shown in Figure 4.



**Figure 4. Carrier Spacecraft Hardware.**

#### 3.1.3 Orbital Lifetime and Probability of Impact

For orbiting or fly-by spacecraft where the baseline mission does not involve impact of such hardware with Mars, operational procedures can be invoked in lieu of accounting for microbial burden.

The maximum probability of accidental impact of a Category III flyby or obiter spacecraft (such as that caused by failure during the cruise phase) shall not exceed  $10^{-2}$ . Launch vehicles, including all stages, must meet a probability of impact of  $10^{-4}$ .

For Mars orbiters or flyby spacecraft that do not meet the maximum total spore burden requirement, orbital lifetime characteristics shall be such that the probability of impact is: 1) less than one percent from launch to launch plus 20 years, and 2) less than five percent between launch plus 20 years to launch plus 50 years.

#### *3.1.3.1 Launch Vehicle (Third Stage) Accidental Impact Avoidance*

A standard analysis for the probability of impact due to the launch vehicle will be performed. The only component of the launch vehicle of interest is the third stage, STAR48 motor. The third stage is the sole component of the launch vehicle injected beyond Earth orbit. A trajectory biasing strategy will ensure the third stage does not impact Mars since it is separated immediately after launch, prior to performing any trajectory corrections maneuvers (TCMs). The probability of the third stage impacting Mars is required to be less than  $10^{-4}$  as defined in NPR 8020.12C. An initial probability-of-impact analysis will be produced in Phase A by the ARES Mission Design sub-team at JPL, and will be updated throughout the mission life cycle, to demonstrate compliance with this requirement.

#### *3.1.3.2 Carrier Spacecraft Impact Avoidance*

In lieu of cleaning the CS to the levels required for a Category IVa mission, ARES has opted to meet orbital lifetime/impact avoidance requirements. A trajectory biasing strategy is used for the initial launch aim point to preclude unnecessary Mars contamination in the event of a post-launch failure. While recent Mars missions have used Type I interplanetary trajectories, trajectory biasing for a Type II interplanetary trajectory as a Planetary Protection strategy has been successfully demonstrated with Mars Global Surveyor (MGS). The launch aim point bias is removed with the successful completion of TCM-2. After TCM-2 is completed, the CS and entry systems will be on a direct entry trajectory for Mars (so that the entry system can perform its direct, ballistic entry). Twelve hours from entry interface, the entry system is separated from the CS. The CS then performs a divert maneuver to fly past Mars and enable the relay phase of the mission. As the CS departs Mars, its path will also be directed to preclude close approach to any other protected planet.

The probability of impact by the spacecraft will be conservatively estimated by the summation of the products of probability of the failure of each discrete TCM  $P_i$ , leading to an impact trajectory and the probability that the next maneuver does not occur (due to a spacecraft failure)  $Q_{i+1}$ . Specifically, the reliability model used for MGS and Mars Climate Orbiter (MCO) will be employed. (Alternatively, ARES may use the standard value for the unreliability of the next maneuver  $Q = 0.01$ ). Since the mission involves hardware that will ultimately contact the Martian surface, the probability  $P_i$  of the last maneuver is the probability that the spacecraft will not be in the nominal entry corridor, but will impact Mars anyway (i.e., will land/impact in a non-nominal manner). For the earlier  $P_i$ , ARES may use as conservative values, the probability of any contact.

An initial analysis will be developed in Phase A with updates performed in Phases B through D. Results of the analyses will be provided to the NASA PPO at major project reviews and documented in the Pre-Launch Planetary Protection Report. Since ARES has opted for the orbital lifetime/ impact avoidance requirements, the CS will need to be assembled in a FED STD 209E class 100,000 or ISO Class 8 clean room per NPR 8020.12C.

The ARES team will also perform a breakup and burnup analysis of the CS to complement the probability of impact analysis. While it is not intended for the CS to enter the atmosphere of Mars, there

is the small probability that CS entry could occur since it will be on a direct Mars entry trajectory until completion of the final divert maneuver. The initial Breakup Analysis Report will be completed early in Phase B. This will allow the CS design team to address simple design modifications that may be necessary to enhance burn-up of the spacecraft in the event of a failure, increasing the confidence level that inadvertent contamination will not occur. The Breakup Analysis Report will be updated in Phase D after completion of the final development. The breakup and burnup analysis will be performed by JPL and LaRC personnel with the results provided to the JPL CS design team. The results of the breakup and burnup analysis as well as the probability of impact analysis will be provided to the NASA PPO at major project reviews and documented in the Pre-Launch Planetary Protection Report.

## **4.0 MARS IMPACTING HARDWARE (CATEGORY IVA)**

Hardware entering the atmosphere of Mars and ultimately ending up on the surface is subject to more stringent planetary protection requirements for cleanliness. All of the ARES launched hardware is bound by the constraints and requirements of NPR 8020.12C, which are detailed in the following sections. These requirements outline maximum tolerable contamination levels on hardware impacting the planet, impact probability requirements for hardware listed as non-impact, clean room hardware assembly specifications, and organic materials inventory specifications.

### **4.1 ESTIMATING BIOLOGICAL CONTAMINATION**

The plan for demonstrating that the biological contamination requirements are met involves the allocation of the microbial burden to parts and assemblies of the spacecraft and the selection of flight assembly candidates for microbial reduction. Certain analyses will be performed to estimate the burden in some special cases. The specific planetary protection requirement for the microbial burden on exposed surfaces, as described in Section 4.1, may not exceed  $3 \times 10^5$  at launch and may not exceed  $5 \times 10^5$  total burden (including encapsulated volumes). The 300 spores/m<sup>2</sup> average burden density Planetary Protection requirement applies to the entire atmospheric flight system, AES, aeroshell inboard surface, backshell and heatshield inboard surface, and backshell outboard surface, and the disc-gap-band parachute.

#### **4.1.1 Clean Room Assembly Requirement**

All Category III and IV mission hardware are required to be assembled and maintained in a FED STD 209E class 100,000 (or ISO Class 8) or higher clean room.

#### **4.1.2 Spacecraft Microbial Limits**

Microbial burden limits are based on the average total pre-sterilization levels for the Viking landers. These limits apply to the number of spores present on the spacecraft and lander at the time of launch.

##### *4.1.2.1 Maximum Surface Microbial Spore Burden*

Surface microbial spore burden applies to all exterior and interior spacecraft surfaces that are exposed, or have the potential of being exposed to the Mars environment due to breakup caused by impact on the surface of Mars.

Category III missions do not have specific surface microbial requirements.

Category IVa mission hardware, including all subsystems that are part of a single landing event, have a maximum surface microbial burden limit of  $3.0 \times 10^5$  at launch and are limited by an average surface spore density  $\leq 300$  spores/m<sup>2</sup>.

Category IVb and IVc mission hardware, including all subsystems that are part of a single landing event, shall have a limit of  $\leq 30$  spores on all free surfaces of the landed system.

#### 4.1.2.2 *Maximum Total Microbial Spore Burden*

Total microbial spore burden comprises all exposed surface spores, spores trapped between mated surfaces of the spacecraft, and spores encapsulated within interior volumes or enclosures.

Category III missions involving Mars orbiters or fly-by spacecraft that do not meet the orbital lifetime probability requirement (See Section 3.1.1) are bound by a limit of  $\leq 5.0 \times 10^5$  spores/vehicle at launch.

Category IV missions involving Mars landers and probes that will make hard landings or non-nominal impacts are bound by a limit of  $\leq 5.0 \times 10^5$  spores/vehicle at launch. This value includes the  $3.0 \times 10^5$  spores/vehicle allocated to exposed exterior and interior surfaces.

### 4.1.3 **Specifications for Bioburden Estimation**

NPR 8020.12C provides specifications for determining microbial burden levels on spaceflight hardware and provides parameters for determining the impact that microbial reduction techniques will have on the expected spore count.

#### 4.1.3.1 *Surface Microbial Density*

Surface microbial burden caused by fallout onto spacecraft surfaces depends on the class of clean room in which the hardware was assembled. The average number of spores on any free surface (non-encapsulated) of spacecraft system, subassembly, or part exposed to the atmosphere of the clean room is given by Table 4.

**Table 4. Specifications for Surface Microbial Density**

<b>Clean Room Classification</b>	<b>Surface Microbial Density</b>
Clean room 10 <sup>4</sup> or better – highly controlled	50 spores/m <sup>2</sup>
Clean room 10 <sup>4</sup> – normal control	$5 \times 10^2$ spores/m <sup>2</sup>
Clean room 10 <sup>5</sup> – highly controlled	$1 \times 10^3$ spores/m <sup>2</sup>
Clean room 10 <sup>5</sup> – normal control	$1 \times 10^4$ spores/m <sup>2</sup>
Uncontrolled manufacturing	$1 \times 10^5$ spores/m <sup>2</sup>

#### 4.1.3.2 *Encapsulated Microbial Density*

Encapsulated microbial burden applies to all non-metallic materials on the spacecraft. The average number of spores buried inside the *i*<sup>th</sup> subassembly or component of a spacecraft can be estimated with the values in Table 5. If source specific density values are used, they must be applied to the entire volume of spacecraft non-metallic material without using the average density value,  $d_v(0)$ . The upper values should be used for determining the microbial burden. A rationale shall be presented for the selection of values less than the maximum of the applicable range specified.



**Table 5. Specifications for Encapsulated and Enclosed Microbial Density**

<b>Encapsulated and Enclosed Region</b>	<b>Surface Microbial Density</b>
Encapsulated Organisms in:	
Electronic piece parts	3 – 150 spores/cm <sup>3</sup>
Other non-metallic materials	1 – 30 spores/cm <sup>3</sup>
System-Wide Average	130 spores/cm <sup>3</sup>
Enclosed surface densities:	
Clean room – highly controlled	0.05 – 0.5 spores/cm <sup>2</sup>
Clean room – normal control	0.5 – 10 spores/cm <sup>2</sup>
Uncontrolled manufacturing	10 – 100 spores/cm <sup>2</sup>

#### 4.1.4 Microbial Reduction Parameters

Measures can be taken to reduce the spore allocation on surfaces and in enclosed volumes by either sterilization or through exposure to dry-heat processes.

##### 4.1.4.1 Time-Temperature for Sterility

An encapsulated, mated, open surface or airborne source may be considered sterile (bioburden equal to zero) if its temperature exceeds 500°C for more than 0.5 seconds. An example would include the encapsulated volume of a camera lens that experienced a molten state during manufacturing. Surface areas of the lens, however, will still have to be cleaned and accounted for.

##### 4.1.4.2 Dry-Heat Microbial Reduction

Specifications covering the microbial reduction experienced through dry-heat process are expressed in terms of D-value and Z-value. The D-value is defined as the time required to destroy 90% of the microbial spores on surfaces or encapsulated volumes of a spacecraft by subjecting it to dry heat at 125°C and 25% relative humidity referenced to standard conditions of 0°C and 760 torr. D-values for various spore locations are:

**Table 6. Standard D-values for Dry Heat Microbial Reduction**

<b>D-Value</b>	<b>Surface or Volume</b>
D <sub>S(125)</sub> = 0.5 hours	Exposed and “free” surfaces
D <sub>M(125)</sub> = 1.0 hours	Mated surfaces
D <sub>B(125)</sub> = 5.0 hours	Non-metallic volumes

The D-value is dependent on the temperature of the dry heat process. If the process is less than 125°C, then the D-value increases according to the parameter called the Z-value. The Z-value defines the change in temperature which produces a factor of 10 change in a given D-value. The Z-value of 21°C is applicable within the temperature range of 104°C to 125°C. The change in D-value is given by Equation 1. In some projects, a Z-value of 15°C is used to provide time margin in the DHMR process.

#### Equation 1. D-Value Temperature Dependence

$$D_T = D_{125} \cdot 10^{\left(\frac{125-T}{Z}\right)}$$

#### 4.1.4.3 *Hardy Organisms*

Due to hardy (heat resistant) organisms, dry heat cycles cannot reduce the microbial burden to zero. Hardy organisms make up about  $1 \times 10^{-3}$  of the total spore count of spacecraft surfaces and nominal dry heat cycles only produces a reduction of 0.1. Therefore, the maximum reduction factor that may be taken for dry heat microbial reduction process is  $10^{-4}$ .

## 4.2 ARES BIOBURDEN ALLOCATION

The current best estimate of bio-burden on the AFS is based on estimated free and enclosed surface areas, mated surfaces, and encapsulated non-metallic volumes of structures and components. Estimates of bio-burden levels assume that all hardware undergoes microbial reduction procedures as described in Sections 4.2.3. Estimates for the aeroshell and entry bio-burdens were derived from MER420-1-109: “Mars Exploration Rover (MER) Project Planetary Protection Plan.” [6]

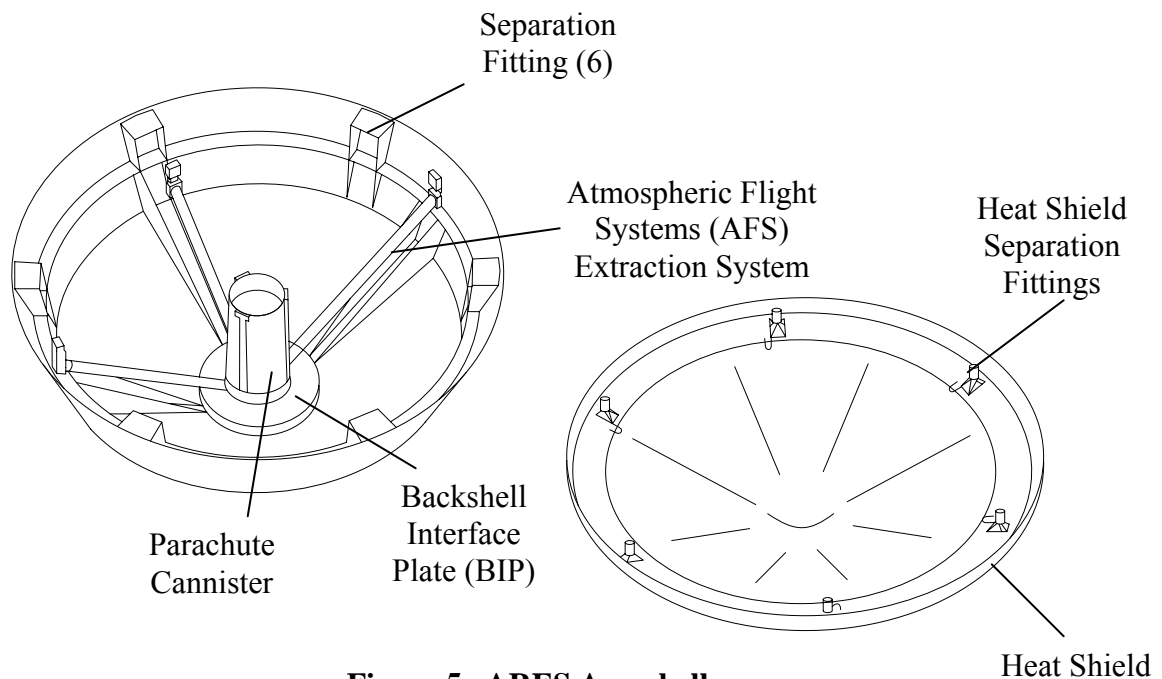
### 4.2.1 Entry, Descent, and Deployment System

#### 4.2.1.1 *Aeroshell*

The aeroshell provides the primary structural load path for the airplane during launch and Mars entry and also serves as the mounting surface for entry and descent electronics and components. The 2.65-m diameter, 12.7 mm thick heatshield and bi-conic backshell are based on Viking, MPF, and MER (Figure 5).

The ARES Project intends to demonstrate that the outboard surface of the heat shield will satisfy the Planetary Protection parameter specification “Time-Temperature for Sterility” during entry heating (see Section 4.2.3). The entry phase will include a large heat pulse with a duration in excess of 10 seconds with surface temperatures in excess of 500°C on the outboard surface of the heatshield. If the heatshield is re-contaminated during launch, this heat pulse will render the heatshield outboard surface absolutely sterile after entry, according to NPR8020.12C. This is an exception in that the bioburden requirement specifies bioburden *at launch* and this assumption, used previously with MPF and MER, will be subject to NASA PPO approval. Conversely, the backshell will not reach 500°C during entry, thus requiring cleaning and assaying of the backshell, CS, fairing, and other surfaces that carry the potential for cross-contamination during launch.

Most aeroshell structural and thermal protection elements will undergo high temperature processes during the manufacture (e.g. curing processes) of the aeroshell components. When possible, high-temperature manufacturing processes will be augmented to provide adequate microbial reduction. When not possible, additional DHMR processes will be performed, at existing JPL or vendor facilities, to provide the maximum microbial reduction.

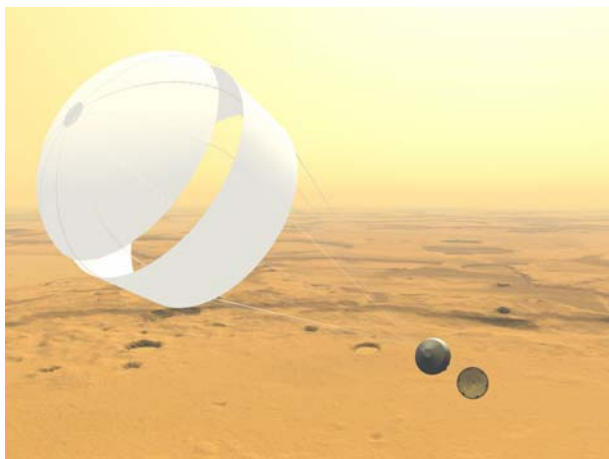


**Figure 5. ARES Aeroshell**

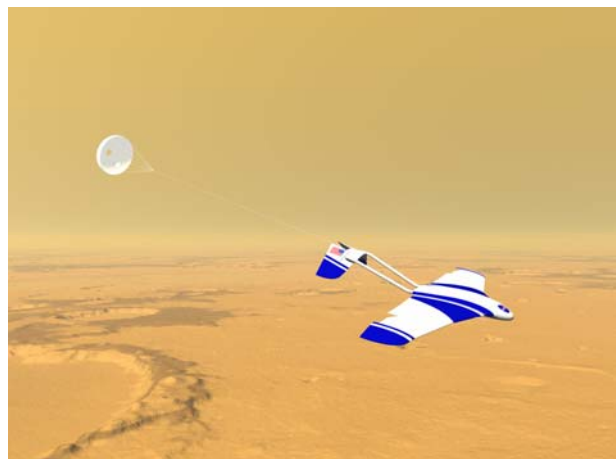
#### 4.2.1.2 Parachutes

The descent parachute subsystem provides deceleration through the transonic phase and creates a stable release environment for the airplane. The entry flight path angle is  $-12^\circ$ . The parachute is a mortar-deployed, 16m Disk Gap Band with the same configuration as the MER parachute but the same size as the one used on Viking, shown in Figure 6. Deceleration to subsonic conditions occurs within 7.5 seconds. Deceleration to the airplane release conditions requires an additional 8 seconds and occurs at approximately 8 km AGL.

The supersonic parachute system (with the mortar charge removed) will undergo the DHMR process. The mortar charge for deploying the supersonic parachute will be cleaned and assayed using alternative procedures, identical to what was used with MER. Additional sterility of the mortar charge is achieved when it is activated, reaching a temperature that will exceed  $500^\circ\text{C}$  for greater than 0.5 seconds.



**Figure 6. Disk Gap Band (DGB) Entry Parachute**



**Figure 7. EDD Drogue Chute**

A drogue chute is used during airplane deployment to augment airplane reorientation and increase drag (Figure 7). Similar to military ordnance systems, the drogue chute is extracted via a static line. The drogue is used to provide the primary orientation force during the airplane unfolding to ensure the nose is pointed in the direction of flight. Once the unfolding and orientation maneuvers are complete, the drogue is released via a pyro line cutter. The drogue riser is attached at the top of the fuselage and passes through a guide eye on the tail. The subsonic orientation drogue parachute will undergo DHMR at existing LaRC facilities prior to delivery to JPL for final integration with the aeroshell.

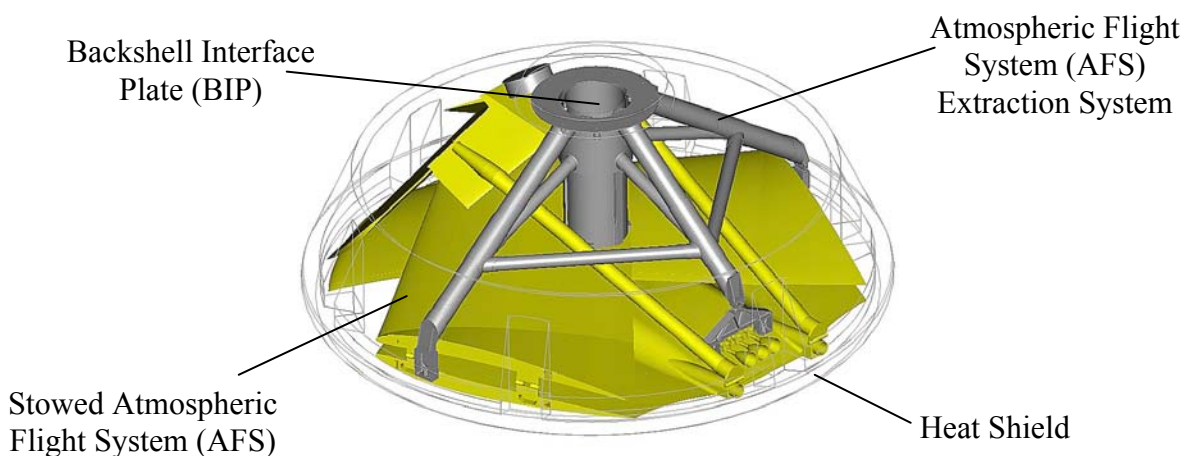
#### 4.2.1.3 *Entry System Power and Avionics*

Entry system power and avionics leverage previous Mars missions (e.g., MER) regarding the components selected so that they are all amenable to use of DHMR and solvent cleaning.

#### 4.2.1.4 *Atmospheric Flight System (AFS) Extraction System*

A dedicated AFS extraction system (AES) is used for mounting the AFS within the aeroshell as well as guiding the AFS out during entry, descent, and deployment, shown in Figure 8. The stowed airplane is attached to the AES through three mounts and to the aeroshell through a single connection near the airplane nose. The MER-based extraction subsystem design uses timers and state measurements to initiate three sets of pyro devices to complete the extraction. Differences in the ballistic coefficient result in differential accelerations to initiate and maintain relative movement between the AES and the backshell, allowing it to move down the parachute canister on a set of triple tandem rollers. Near the end of travel, the extractor initiates the final set of pyros (3) releasing the AFS from the AES.

The AES structure is a blend of composite and titanium elements. After fabrication, the final assembly will include contamination control, solvent cleaning, and DHMR to achieve the bio-burden allocation. The AES is provided by LaRC and will be cleaned using existing LaRC facilities prior to delivery to JPL for final integration with the aeroshell.



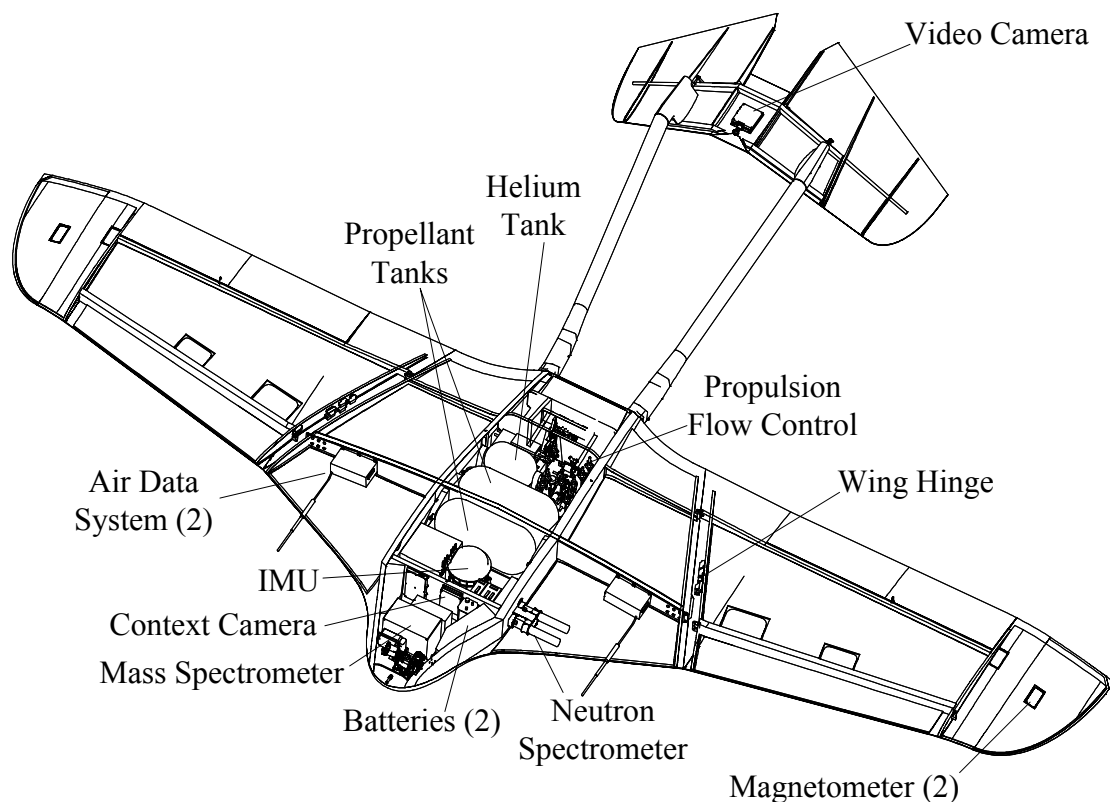
**Figure 8. AFS Extraction System**

#### 4.2.2 Atmospheric Flight System

The atmospheric flight system airframe is comprised of a blended fuselage body with removable upper surface center skin, symmetric left and right wing panels, and a tail empennage. Airframe skins and internal structure are fabricated as composite sandwich systems with space qualified carbon fabric/epoxy or cyanate-ester materials and perforated aluminum honeycomb core. The tail assembly is comprised of two unidirectional carbon/epoxy tape booms mounted through faired pylons to a single inverted “V” stabilizer with large balanced control surfaces. The stabilizer is a composite sandwich structure with forward and aft solid laminate spars. The airplane is propelled by a bipropellant (MMH and MON-3) propulsion subsystem with three 22-N thrusters. The Airplane subsystems include (shown in Figure 9):

- Telecommunications
- Command & Data Handling
- Attitude Determination & Control
- Power
- Thermal
- Structures & Mechanisms
- Propulsion
- Spacecraft Support

The ARES science instrument suite includes a pair of magnetometers, a mass spectrometer, a neutron spectrometer, a context camera, and a video camera, a pair of atmospheric data systems, and an entry data system.



**Figure 9. Subsystems of the ARES Atmospheric Flight System**

The composite airframe, including the majority of interior components and the drogue chute, will undergo 200 hours of DHMR at 110°C. Analysis will demonstrate that this process will achieve four orders-of-magnitude reduction in the biological burden. All components that will undergo DHMR are qualified to meet the time-temperature requirements, according to vendor specifications.

Components that cannot be subject to dry heat, such as cameras, the MIMU, the Li-SO<sub>2</sub> batteries, and some electronics boards, will be cleaned through a combination of component level DHMR and solvent cleaning. Components not subjected to DHMR will be assembled in a class 10,000 or better clean room. When possible, biological assay sampling during manufacture will be performed to determine bioburden levels on interior surfaces of the components. The project will work with suppliers to determine the best approach to cleaning or sterilizing each component that will satisfy both Planetary Protection and component qualification requirements.

#### **4.2.3 ARES Contamination Analysis (Category IVa)**

With the EDD and AFS systems being a Category IVa mission, NPR 8020.12C requires the entry system and its contents be assembled in a FED STD 209E class 100,000 clean room. Since both the systems ultimately impact the surface of Mars, ARES will assume that all enclosed surfaces carry the potential to break apart on impact. Therefore the biological burden on every interior, enclosed, and mated surface, and in all encapsulated volumes is accounted for in the bio-burden allocations. The EDD system is made up of a significant amount of hardware (See Section 1.1) with numerous encapsulated volumes and surfaces where biological spores can exist.

Determining microbial burden allocations for the AFS hardware required detailed dimensions and specifications of all components and subsystems making up the airplane. Enclosed surfaces, exposed surfaces, enclosed volumes and encapsulated volumes were determined for each component. For ARES pre Phase-A study, mated surfaces were not tallied and a conservative assumption of the total mated area of ARES hardware was assumed, and accounted for as free surface spores. For the Entry and Descent systems, allocations were derived from the MER Planetary Protection Plan [6].

#### 4.2.4 Hardware Microbial Reduction Strategy

The baseline strategy for achieving the needed threshold cleanliness levels is illustrated in Table 7. Hardware undergoes either DHMR, solvent and wipe cleaning, or is subjected to other microbial reduction processes such as entry heating. The table also outlines which organization will be responsible for cleaning of particular hardware and subsystems.

**Table 7. ARES Hardware Microbial Reduction Strategy**

System	Subsystem	Microbial Reduction Process			Responsible Organization
		DHMR	Solvents	Other	
EDD	Aeroshell	✓		✓	JPL
EDD	Supersonic Parachute	✓			JPL
EDD	Mortar for supersonic parachute		✓	✓	JPL
EDD	Batteries		✓	✓	JPL
EDD	PIU		✓		JPL
EDD	Cable Harnesses	✓			JPL
EDD	Subsonic Droque	✓			LaRC
EDD	AES	✓			LaRC
EDD	Sep. Nuts		✓		JPL
EDD	Science – Entry Data System	✓	✓		LaRC
AFS	Structures & Mechanisms	✓			LaRC
AFS	Command & Data Handling	✓			LaRC
AFS	ADCS* – MIMU		✓	✓	LaRC
AFS	ADCS – Control Actuator Subsystem	✓			LaRC
AFS	ADCS – Air Data Subsystem	✓	✓		LaRC
AFS	ADCS – Radar Altimeter	✓			LaRC
AFS	EPS - Batteries		✓		LaRC
AFS	EPS – Isolation & Switching	✓			LaRC
AFS	Harnesses	✓			LaRC
AFS	Propulsion	✓			LaRC
AFS	Telecom	✓			LaRC
AFS	Thermal	✓			LaRC
AFS	Science Payload - Magnetometer	✓			LaRC
AFS	Science Payload - Mass Spectrometer	✓			LaRC
AFS	Science Payload - Neutron Spectr.	✓			LaRC
AFS	Science Payload - Cameras		✓	✓	LaRC

\*ADCS – Attitude Determination and Control Subsystem

#### 4.2.5 ARES Bioburden Allocation

Table 8 shows the detailed method of calculating expected final microbial burden for each component, subsystem, and for the total AFS. Once the accountable surfaces and volumes were determined, surface spore burden was calculated based on the clean-room classification in which the hardware will be assembled (See Section 4.1.3.1). For encapsulated volumes, spore burden is based on whether the volume comprises electronic pieces/parts or is made up of other non-metallic materials (See Section 4.1.3.2), such as the composite laminate making up the wings and fuselage of the airplane.

Once the total microbial burden is determined for the hardware, a microbial reduction strategy is identified. For the ARES pre Phase-A study, either dry heat microbial reduction (DHMR) or alcohol wiping were the techniques assumed. For any surface being cleaned by alcohol wiping, a  $10^4$  reduction in spore density is assumed. This is a conservative assumption since wiped surfaces can be assayed and proven to be sterile (i.e. allocation of zero spores). For DHMR, microbial reduction is based on the planetary protection specification of D-value and Z-value, outlined in Section 4.1.4.2. Mars programs typically use a decreased Z-value =  $15^{\circ}\text{C}$  to provide for increased margin when determining number of hours for which dry heat will be used. The corresponding D-values associated with this reduced Z-value and a dry-heat temperature of  $110^{\circ}\text{C}$  (based on Equation 1), are  $D_{S(T)}=5.0$  for free surfaces and  $D_{B(T)}=50.0$  for encapsulated volumes.



**Table 8. Atmospheric Flight System (AFS) Microbial Burden Analysis**

	Accountable Surface [cm <sup>2</sup> ]	Accountable Encap. Volume [cm <sup>3</sup> ]	Assembly Clean Room Class	Flight Units	Surface Spores	Encap. Spores	Total Spores (Pre-Microbial Reduction)	Microbial Reduction Method	Final Surface Spores	Final Encap. Spores	Final Spore Count
<b>Atmospheric Flight System</b>											
<b>Telecommunications Subsystem</b>							2.85E+05		0		2.86E+01
UHF Transceiver w/Diplexer	1322	1886	10 <sup>5</sup> NC	1	1322	282938	284260	Dry Heat	0	28	29
UHF Patch Antenna (RHCP)	200	0	10 <sup>5</sup> NC	1	200	0	200	Dry Heat	0	0	0
UHF Linear Antenna	150	0	10 <sup>5</sup> NC	1	150	0	150	Dry Heat	0	0	0
UHF TTL Antenna Selector Switch	0	0	10 <sup>5</sup> NC	1	0	0	0	Dry Heat	0	0	0
UHF RX Band Notch Filter	0	0	10 <sup>5</sup> NC	1	0	0	0	Dry Heat	0	0	0
<b>Command &amp; Data Handling Subsystem</b>							4.55E+05		0		4.64E+01
Comm & Payload Interface (CAPI) Board	515	350	10 <sup>5</sup> NC	1	515	52500	53015	Dry Heat	0	5	5
SOH Monitor & Attitude (SMACI) Board	515	350	10 <sup>5</sup> NC	1	515	52500	53015	Dry Heat	0	5	5
CASI Board	515	350	10 <sup>5</sup> NC	1	515	52500	53015	Dry Heat	0	5	5
Power Distribution (PDB) (PAPI Board)	515	350	10 <sup>5</sup> NC	3	1545	157500	159045	Dry Heat	0	16	16
Power Converters / Conditioners	258	175	10 <sup>5</sup> NC	1	258	26250	26508	Dry Heat	0	3	3
SACI Board	515	350	10 <sup>5</sup> NC	1	515	52500	53015	Dry Heat	0	5	5
Processor Card & Motherboard	515	350	10 <sup>5</sup> NC	1	515	52500	53015	Dry Heat	0	5	5
Chassis (8 board)	4256	0	10 <sup>5</sup> NC	1	4256	0	4256	Dry Heat	0	0	1
<b>Attitude Determination &amp; Control Subsystem</b>							4.37E+05		5.53E+02		1.51E+05
IMU-MIMU	11060	1000	10 <sup>4</sup> NC	1	553	150000	150553	Wipe	553	150000	150968
Radar Altimeter	1280	410	10 <sup>5</sup> NC	1	1280	61500	62780	Dry Heat	0	6	6
Radar Altimeter Antennas	181	0	10 <sup>5</sup> NC	2	362	0	362	Dry Heat	0	0	0
Radar Altimeter Absorber, Misc.	816	98	10 <sup>5</sup> NC	2	1632	5880	7512	Dry Heat	0	1	1
Air Data System Electronic Boards	515	350	10 <sup>5</sup> NC	2	1030	105000	106030	Dry Heat	0	11	11
Air Data System Probe	100	0	10 <sup>5</sup> NC	2	200	0	200	Dry Heat	0	0	0
Air Data System Tubing	100	0	10 <sup>5</sup> NC	2	200	0	200	Dry Heat	0	0	0
CAS Actuators & Resolvers	250	0	10 <sup>5</sup> NC	6	1500	0	1500	Dry Heat	0	0	0
CAS Controller Boards	515	350	10 <sup>5</sup> NC	2	1030	105000	106030	Dry Heat	0	11	11
CAS Controller Board Enclosure	1400	0	10 <sup>5</sup> NC	1	1400	0	1400	Dry Heat	0	0	0
<b>Power Subsystem</b>							1.71E+04		8.92E+03		8.92E+03
Avionics Battery (Battery 1)	3965	0	10 <sup>5</sup> NC	1	3965	0	3965	Wipe	3965	0	3965
Switching Devices Battery (Battery 2)	4956	0	10 <sup>5</sup> NC	1	4956	0	4956	Wipe	4956	0	4956
Avionics Battery Case	2852	0	10 <sup>5</sup> NC	1	2852	0	2852	Dry Heat	0	0	1
Switching Devices Battery Case	3366	0	10 <sup>5</sup> NC	1	3366	0	3366	Dry Heat	0	0	1
Isolation Switches and Chassis	1960	0	10 <sup>5</sup> NC	1	1960	0	1960	Dry Heat	0	0	0

	Accountable Surface [cm <sup>2</sup> ]	Accountable Encap. Volume [cm <sup>3</sup> ]	Assembly Clean Room Class	Flight Units	Surface Spores	Encap. Spores	Total Spores (Pre-Microbial Reduction)	Microbial Reduction Method	Final Surface Spores	Final Encap. Spores	Final Spore Count
<b>Thermal Subsystem</b>							8.14E+05		8.25E+00		8.96E+01
Insulation	36136	8351	10 <sup>5</sup> NC	2	72271	501060	573331	Dry Heat	7	50	65
Heat Sinks	100	0	10 <sup>5</sup> NC	1	100	0	100	Dry Heat	0	0	0
Thruster Radiant Reflector Shield	200	0	10 <sup>5</sup> NC	1	200	0	200	Dry Heat	0	0	0
Thermofoil Heaters	133	0	10 <sup>5</sup> NC	40	5307	1194	6501	Dry Heat	1	0	1
DC Temperature Controllers	90	25	10 <sup>5</sup> NC	40	3600	150000	153600	Dry Heat	0	15	16
Thermal Switch	100	50	10 <sup>5</sup> NC	3	300	22500	22800	Dry Heat	0	2	2
Temperature Sensors	50	25	10 <sup>5</sup> NC	15	750	56250	57000	Dry Heat	0	6	6
<b>Structures &amp; Mechanisms Subsystem</b>							3.94E+06		3.06E+01		4.24E+02
Fuselage / Centerbody	42492	10644	10 <sup>5</sup> NC	1	42492	319316	361808	Dry Heat	4	32	40
Wing Panels	111384	45197	10 <sup>5</sup> NC	2	222768	2711806	2934574	Dry Heat	22	271	316
Tail Assembly	40824	20046	10 <sup>5</sup> NC	1	40824	601370	642194	Dry Heat	4	60	68
<b>Propulsion Subsystem</b>							4.55E+05		2.69E+00		4.82E+01
Bipropellant Thrusters	230	0	10 <sup>5</sup> NC	3	690	0	690	Dry Heat	0	0	0
Valves for Bipropellant Thrusters	79	0	10 <sup>5</sup> NC	6	474	0	474	Dry Heat	0	0	0
Propellant Tank Shell & Stiffeners	4618	0	10 <sup>5</sup> NC	2	9236	0	9236	Dry Heat	1	0	2
Propellant Management Device (PMD)	0	0	10 <sup>5</sup> NC	2	0	0	0	Dry Heat	0	0	0
Helium Pressurant Tank	4518	2328	10 <sup>5</sup> NC	1	4518	69840	74358	Dry Heat	0	7	8
Check Valves	28	0	10 <sup>5</sup> NC	4	112	0	112	Dry Heat	0	0	0
Helium Regulator	182	0	10 <sup>5</sup> NC	1	182	0	182	Dry Heat	0	0	0
Liquid Filter (MMH & MON3)	91	0	10 <sup>5</sup> NC	2	182	0	182	Dry Heat	0	0	0
HP Service Valves	74	0	10 <sup>5</sup> NC	11	814	0	814	Dry Heat	0	0	0
GHe HP Filter	58	0	10 <sup>5</sup> NC	1	58	0	58	Dry Heat	0	0	0
NC Pyro. Valves	50	0	10 <sup>5</sup> NC	5	250	0	250	Dry Heat	0	0	0
High Pressure Transducer	105	60	10 <sup>5</sup> NC	1	105	9000	9105	Dry Heat	0	1	1
Low Pressure Transducer	105	60	10 <sup>5</sup> NC	4	420	36000	36420	Dry Heat	0	4	4
Flow Venturis	25	0	10 <sup>5</sup> NC	2	50	0	50	Dry Heat	0	0	0
Propellant Isolation Assembly (PIA) Plate	3406	3406	10 <sup>5</sup> NC	1	3406	102180	105586	Dry Heat	0	10	11
Pressurant Control Assembly (PCA) Plate	3406	3406	10 <sup>5</sup> NC	1	3406	102180	105586	Dry Heat	0	10	11
Thruster Valve Controller	450	725	10 <sup>5</sup> NC	1	450	108750	109200	Dry Heat	0	11	11
Thruster Valve Controller Chassis	1136	0	10 <sup>5</sup> NC	1	1136	0	1136	Dry Heat	0	0	0
Lines, Tubing, Fittings	1247	0	10 <sup>5</sup> NC	1	1247	0	1247	Dry Heat	0	0	0
Tank Support Brackets	200	0	10 <sup>5</sup> NC	1	200	0	200	Dry Heat	0	0	0
<b>Spacecraft Support Instrumentation</b>							6.55E+04		0		6.66E+00
High Pressure Transducer - Helium	105	60	10 <sup>5</sup> NC	1	105	9000	9105	Dry Heat	0	1	1
Low Pressure Transducer - MMH & MON3	105	60	10 <sup>5</sup> NC	2	210	18000	18210	Dry Heat	0	2	2
Cables, Harnesses, & Connectors	230	0	10 <sup>5</sup> NC	1	230	0	230	Dry Heat	0	0	0
Temperature Sensors	50	25	10 <sup>5</sup> NC	10	500	37500	38000	Dry Heat	0	4	4

	Accountable Surface [cm <sup>2</sup> ]	Accountable Encap. Volume [cm <sup>3</sup> ]	Assembly Clean Room Class	Flight Units	Surface Spores	Encap. Spores	Total Spores (Pre-Microbial Reduction)	Microbial Reduction Method	Final Surface Spores	Final Encap. Spores	Final Spore Count
<b>Science Payload</b>							8.90E+05		1.02E+02		4.97E+04
Magnetometer - Sensor	42	18	10 <sup>5</sup> NC	2	84	5400	5484	Dry Heat	0	1	1
Magnetometer - Sensor & Thermistor Cable	500	0	10 <sup>5</sup> NC	2	1000	0	1000	Dry Heat	0	0	0
Magnetometer - Connectors	0	0	10 <sup>5</sup> NC	2	0	0	0	Dry Heat	0	0	0
Magnetometer - Electronics Cards	645	615	10 <sup>5</sup> NC	2	1290	184500	185790	Dry Heat	0	18	19
Magnetometer - Electronics Chassis	3612	0	10 <sup>5</sup> NC	1	3612	0	3612	Dry Heat	0	0	1
Mass Spectrometer	1875	2010	10 <sup>5</sup> NC	1	1875	301500	303375	Dry Heat	0	30	31
Mass Spectrometer Pyro & Initiator	69	0	10 <sup>5</sup> NC	1	69	0	69	Dry Heat	0	0	0
Context Camera	1790	110	10 <sup>4</sup> NC	1	90	16500	16590	Wipe	90	16500	16634
Neutron Spectrometer Sensor	1500	915	10 <sup>5</sup> NC	1	1500	137250	138750	Dry Heat	0	14	14
Neutron Spectrometer Data Module	1075	1339	10 <sup>5</sup> NC	1	1075	200850	201925	Dry Heat	0	20	20
Video Camera	230	220	10 <sup>4</sup> NC	1	12	33000	33012	Wipe	12	33000	33017
<b>Atmospheric Flight System - Subsystems (TOTAL)</b>							<b>7.36E+06</b>		<b>1.0E+04</b>		<b>2.10E+05</b>

Highest Post DHMR Spore Counts	Spores
IMU-MIMU	1.5E+05
Video Camera	3.3E+04
Context Camera	1.7E+04
Switching Devices Battery (Battery 2)	5.0E+03
Avionics Battery (Battery 1)	4.0E+03
Wing Panels	3.2E+02
Tail Assembly	6.8E+01
Insulation	6.5E+01
Fuselage / Centerbody	4.0E+01
Mass Spectrometer	3.1E+01

Dry Heat Temp [°C]=		<b>110</b>	Hours=	<b>200</b>
Z <sub>value</sub> =	D <sub>s(T)</sub> =	D <sub>B(T)</sub> =		
(21 standard)	0.5	5	< D-values at 125°C	
<b>15</b>	<b>5.00</b>	<b>50.00</b>	< D-values at 110°C	

The preliminary ARES surface and total microbial spore allocations are given in Table 9. These allocations are based on the final spore count from the analysis discussed above but typically rounded to 2 significant digits or rounded up to the nearest order of magnitude.

The hardware which will provide the most challenge for reducing microbial bioburden are those components which are not capable of tolerating the dry-heat conditions of DMHR. These components include: the IMU-MIMU, video and context cameras, and the two airplane battery clusters. Special procedures will be required for these components, such as manufacture and assembly in higher class clean-rooms, or removal of certain parts or components to undergo DMHR, then reassembly. Such details are typically outlined in the follow-on Planetary Protection Implementation Plan.

The AFS has an estimated total surface area of approximately  $50 \text{ m}^2$ , resulting in a surface spore density of  $200 \text{ spores/m}^2$ , providing a 33% reserve against the required  $300 \text{ spores/m}^2$ . Surface area estimates for the EDD will be performed in Phase-A to confirm the surface burden density meets this requirement. With reserves, allocation levels meet the Planetary Protection requirements specified in Section 4.1.

**Table 9. ARES Bioburden Allocation**

System	Subsystem	Surface Microbial Spore Estimate	Total Microbial Spore Estimate	Comments
EDD	Heatshield (inboard)	$2.5 \times 10^3$	$2.5 \times 10^3$	Derived from MER 420-1-109
EDD	Backshell (in and out-board)	$5.0 \times 10^3$	$5.0 \times 10^3$	Derived from MER 420-1-109
EDD	Backshell (other)	$1.0 \times 10^4$	$1.0 \times 10^4$	Derived from MER 420-1-109
EDD	Parachutes	$2.5 \times 10^3$	$2.5 \times 10^3$	Derived from MER 420-1-109
EDD	Non-Exposed Surfaces	$1.0 \times 10^5$	$1.0 \times 10^5$	Derived from MER 420-1-109
EDD	AFS Extraction System	$7.0 \times 10^4$	$7.0 \times 10^4$	
<b>EDD</b>	<b>Total EDD Estimate</b>	<b><math>1.9 \times 10^5</math></b>	<b><math>1.9 \times 10^5</math></b>	
AFS	Telecommunications	$1.0 \times 10^2$	$1.0 \times 10^2$	
AFS	Command & Data Handling	$1.0 \times 10^2$	$1.0 \times 10^2$	
AFS	Attitude Determination	$5.5 \times 10^2$	$1.5 \times 10^5$	MIMU – No DHMR
AFS	Power Subsystem	$8.2 \times 10^3$	$9.0 \times 10^3$	LiSO <sub>2</sub> Batteries – No DHMR
AFS	Thermal Subsystem	$1.0 \times 10^2$	$1.0 \times 10^2$	
AFS	Structures & Mechanisms	$5.0 \times 10^2$	$5.0 \times 10^2$	
AFS	Propulsion	$1.0 \times 10^2$	$1.0 \times 10^2$	
AFS	Cable Harnesses	$1.0 \times 10^2$	$1.0 \times 10^2$	
AFS	Science Payload	$2.5 \times 10^2$	$5.0 \times 10^4$	Cameras – No DHMR
<b>AFS</b>	<b>Total AFS Estimate</b>	<b><math>1.0 \times 10^4</math></b>	<b><math>2.1 \times 10^5</math></b>	
	<b>EDD &amp; AFS Total</b>	<b><math>2.0 \times 10^5</math></b>	<b><math>4.0 \times 10^5</math></b>	
	<b>Margin</b>	<b><math>1.0 \times 10^5</math></b>	<b><math>1.0 \times 10^5</math></b>	
	<b>Max. Allowable Limit</b>	<b><math>3.0 \times 10^5</math></b>	<b><math>5.0 \times 10^5</math></b>	

## 5.0 VERIFYING MICROBIAL BURDEN ALLOCATIONS

Verifying the bioburden allocations and compliance with Planetary Protection requirements is accomplished through statistical sampling and assays of surfaces of the atmospheric flight system, spacecraft, and aeroshell. The sampling techniques and strategies will be outlined in greater detail in the “Planetary Protection Implementation Plan.” Details are discussed in NASA Handbook NHB 5340.1B [7].

### 5.1.1 Sampling Plan

The “Planetary Protection Implementation Plan” will include a detailed samples plan and schedule based on statistical analysis of assayed data, similar to Viking, MPF, and MER plans.

Surfaces will be scheduled for sampling at the last physical access and just after final cleaning. All surfaces must be sampled and assayed before becoming inaccessible during integration and assembly. Prior to shipment of hardware to KSC, cleaning and assaying of the exterior surfaces of the AFS, and the inboard surfaces of the aeroshell will be made to determine the status of the hardware cleanliness. These surfaces will be cleaned again before final aeroshell closeout.

The “Planetary Protection Implementation Plan” will include a table consisting of surfaces to be assayed, estimates areas of those surfaces, burden allocation and approximate dates when these surfaces will be samples. An example is shown in Table 10.

**Table 10. Example Summary Bioassay Schedule**

Hardware Assayed	Bioassay Type	ATLO Step Tied to Schedule	Approx. Dates
Backshell inboard surfaces	Status	Aeroshell closeout	
	Last Access Assay		
	Verification		
	Pre-ship to KSC		
	Post-ship to KSC (spot check)		
	Final/Verification		
Heatshield inboard surfaces	Final/Verification	Aeroshell closeout	

### 5.1.2 Final Bioburden Determination

A statistical analysis will be performed on the assay data to determine the final (actual) microbial bioburden that exists on the flight hardware.

#### 5.1.2.1 *Calculation of Surface Bioburden Density and Number of Spores from Assay Data*

From the assay data, two main values will be calculated: an estimated exposed area-averaged surface burden density, and the estimated total number of spores divided by the total exposed surface area.

From the allocation table discussed in Section 5.1.1, bioburden densities for each hardware element will be used to estimate total exposed surface bioburdens (number of spores). For complicated cases where certain parts of an assembly are dry heat treated without assay and protected, and other parts of the same assembly or surface are dry heat treated then not protected, the burden density for each individual surface must be separately calculated. Once all of the surfaces are calculated, then the number of spores on each hardware item and its burden accountable area are added to obtain the spacecraft total. Also, the average burden density for the complete system is determined by dividing the total number of spores by the total accountable area.

#### 5.1.2.2 *Surface Bioburden Density and Number of Spores without Assay Data*

For surfaces that cannot be assayed, Planetary Protection Specification, “Surface Microbial Density ( $d_s(0)$ )” (NPG 8020.12C) permits the use of a set value for spore density. Section 4.1 provides spore densities for various clean room environments. Uncontrolled manufacturing provides the worst case spore density of  $10^5$  spores/m<sup>2</sup>.

#### 5.1.2.3 *Surface Bioburden Density and Number of Spores for Hardware Treated by a Microbial Reduction Process*

An initial value of spore density will be assumed, as permitted by the Planetary Protection Specification, “Surface Microbial Density ( $d_s(0)$ )” (NPG 8020.12C) for surfaces treated by microbial reduction processes. As discussed in Section 4.1.3, dry heat microbial reduction will be assumed to reduce the burden by a factor of  $10^4$ . Thus any surface exposed by uncontrolled manufacturing would be reduced to 10 spores/m<sup>2</sup>.

### 5.1.3 Total Bioburden

Final microbial burden limits of the spacecraft, aeroshell, and AFS must fall below the required maximum limits outlined in Section 4.1.

## **6.0 PREVENTING RECONTAMINATION**

Measures and procedures must be implemented to prevent undesired increase in microbial burden after spore levels have been established by assay, microbial reduction procedures, or after clean room assembly. Examples of recontamination threats include re-work of assemblies or exposing already cleaned surfaces to unclean hardware or environments. Also, transport of hardware to launch facilities, access to launch vehicle fairing during launch preparations, and particle transport during launch all pose the threat of recontamination.

### **6.1.1 Hardware Assembly and Integration**

The “Planetary Protection Implementation Document” will outline clean room procedures to prevent the increase of bio-burden levels on hardware and components during assembly and integration. For surfaces that have already been cleaned or undergone DHMR, further exposure to the environment will be minimized by bagging, draping, and “remove before flight” covers. The heatshield and backshell will be almost continually covered except when assays of onboard surfaces are being taken. For ground support equipment and non-flight hardware entering the clean room, alcohol wiping will be used to clean surfaces to an expected level of 300 spores/m<sup>2</sup>. This is an expected level and will not be confirmed through assays.

### **6.1.2 Launch and Cruise Operations**

The entry system, rated Category IVa, is mechanically attached to the spacecraft which is rated a Category III. To maintain the appropriate rating for the entry system, special operating procedures and cross contamination prevention techniques are employed. Recontamination of the heat shield is not a concern since it will undergo a heat pulse, sterilizing the surface (See Section 4.2.1), however the backshell will not experience this heat pulse and must therefore be protected from cross contamination from the CS and launch vehicle. Cross contamination of the AFS and AES is prevented through the use of a bio-barrier, formed by sealing the backshell and heatshield. Other options to prevent recontamination of the backshell will be considered in the future, leveraging the strategies employed by MER and to be used by Phoenix and MSL.

## **7.0 ORGANIZATION AND RESPONSIBILITY**

All ARES team members have a role in planetary protection. JPL provides the overall leadership and management of the ARES Planetary Protection effort and acts as the single point of contact between the NASA HQ PPO and the Project. JPL also provides the oversight/ insight and auditing function for the ARES Planetary Protection effort. JPL is responsible for performing all necessary Planetary Protection efforts associated with the Entry and Descent elements. LaRC is responsible for performing all the Planetary Protection efforts associated with the Deployment segment and the AFS. JPL will provide training for the LaRC personnel responsible for the Planetary Protection, with JPL providing the periodic auditing of the LaRC function.

### **7.1 BIOLOGICAL CONTAMINATION CONTROL**

LaRC will implement any biological contamination control procedures at LaRC facilities. JPL will implement any biological contamination control procedures at JPL facilities. JPL will specify requirements and monitor compliance by KSC personnel at KSC and CCAFS facilities, except the launch pad, and by launch vehicle personnel at the launch pad.

Any cleaning procedures for the ARES Entry and Descent hardware will be implemented by JPL. Any cleaning procedures for the ARES Deployment and Atmospheric Flight hardware will be implemented by LaRC

Any cleaning procedures for the launch vehicle will be implemented by the launch vehicle contractor.

### **7.2 MICROBIOLOGICAL MANAGEMENT AND OPERATIONS**

All ARES microbiological sampling and assay activities will be conducted in accordance with the Microbiological Assay Plan, Section 5.1.1, with the use of a standard set of procedures per NHB 5340.1B. As appropriate, the minor details of the Viking Assay and Monitoring Procedure may be adopted.

All independent verification microbiological sampling and assay activities will be conducted, at the discretion of the NASA PPO, with the use of the same standard set of procedures.

All sampling of the ARES and launch vehicle hardware shall be conducted by JPL. The sampling for verification assays (see below) shall be witnessed by the NASA PPO designated microbiological team.

Verification assays at JPL, at CCAFS, and at KSC, exclusive of sampling, shall be performed by a microbiological team designated by the NASA PPO. Participation of the NASA PPO designated team in any bioassay shall constitute the independent verification of bioassays as defined in NPG 8020.12C.



## 8.0 PLANETARY PROTECTION DESIGN AND ANALYSIS PLANNED ACTIVITIES

In Phase-A and B, the bio-burden model will be expanded and refined to include dimensions of hardware directly from computer solid-models of the airframe and components, providing higher fidelity encapsulated volumes and surface area estimates over the current conservative estimates. Specific estimates of the mated surface areas will be included in the Phase A update to the bio-burden model, whereas mated surfaces are treated as enclosed surface areas for the estimates identified previously. Additionally, the EDD surface estimates will be updated to confirm compliance with the bio-burden surface density requirement on the EDD system.

The vehicle assembly and integration concept will be refined in Phase-A to address removal and installation of heat sensitive hardware to preclude damage during the DHMR of any major integrated assemblies of the AFS and EDD system. Hardware not undergoing DHMR will require removal from the airframe, special cleaning by methods described above, and re-installation after the conclusion of the AFS and EDD DHMR. The ARES thermal model is employed to demonstrate proper heating of internal components to the required 110°C during DHMR.

Also in Phase-A, ARES will address the issue of *Special Regions* as it relates to Planetary Protection requirements. ARES will demonstrate that the entry ellipse and AFS flight path do not jeopardize regions on the surface within which terrestrial organisms have the potential to survive. Additionally, ARES will demonstrate that end-of-flight landing of the AFS on the surface will not create an *Induced Special Region*. ARES will conduct an impact analysis to demonstrate a maximum crater depth of <5 meters upon landing in the worst case orientation at the worst case maximum energy level. Using the guidelines provided in MEPAG Special Regions Report April 2006, the deepest crater which could be estimated for Mars using the total mass at Mars (CS + Entry System) at the softest soil (1000 kg/m<sup>3</sup> density), impacting normal to the surface at 4000 m/s, is 4.2 m, which is less than the 5.0 m guideline upper limit. Assessments of the induced special region due to residual heat within the AFS and EDD elements, including mitigation strategy definition, will be performed in Phase B.

As previously discussed, an initial probability-of-impact analysis will be produced in Phase A by the ARES Mission Design team at JPL, with updates throughout the mission life cycle, to demonstrate the probability of the STAR48 third stage impacting Mars meets the required  $10^{-4}$  as defined in NPR 8020.12C. Initial planning of the CS breakup and burnup analysis will be initiated in Phase A to enable the detailed analysis to start early in Phase B. Since the CS will perform a Mars fly-by, a long term orbit propagation analysis is planned to be performed by the ARES Mission Design staff at JPL in Phase-A, with updates in Phases B-E, to demonstrate ARES meets the orbital lifetime/impact avoidance requirements.

**Table 11. Continued Planetary Protection Activities**

<b>Activity</b>	<b>Purpose</b>
Bio-burden Model Refinement	Calculate higher fidelity estimates of encapsulated volume and surface area.
Vehicle Assembly and Integration Concept	Define procedure for removal and installation of hardware during DHMR
Thermal Model Exercise	Demonstrate proper heating of internal components
“Spacecraft” Induced Special Region Analysis	Provide analytic evidence of adequately low probability of impact and absence of special regions.  Perform analysis of component residual heat inducing a special region (Phase B).
CS Breakup and Burnup Analysis	Define analysis limits, environment assumptions, and initial conditions with detailed analysis performed in Phase B.
CS Long Term Orbit Propagation	Perform 50- year orbit propagation analysis to verify no Mars impact occurs.

## **9.0 PLANETARY PROTECTION DOCUMENTATION**

ARES will develop the required plans and procedures as defined in NPG 8020.12C. JPL will lead the development of these plans and procedures, with the implementing organizations providing details specific to their systems and requirements. Detailed documentation of the plans and procedures will be submitted to the PPO for concurrence that requirements are met. Regular Project Management reports will include progress toward meeting Planetary Protection milestones. The key plans and procedures to be developed are identified in Table 12.

Additional project specific plans and reports will be used to implement, maintain, and monitor the Planetary Protection strategy. Those reports are not required to be submitted to the NASA PPO, however, the reports and findings are always available to the NASA PPO, or his/her designated representative for review or audit. Members of the Biotechnology & Planetary Protection Group at JPL will assist ARES in developing these documents, and implementing the associated requirements. The organic materials list will be compiled and the required samples collected by LaRC for the airplane and science payload, and by JPL for the EDD and CS. The combined organic materials list will be reported in the Pre-Launch Planetary Protection Report. The organic materials samples will be collected by the organizations building the hardware, then archived at JPL by the Biotechnology and Planetary Protection Group.

### **9.1 PLANETARY PROTECTION IMPLEMENTATION DOCUMENT**

The “ARES Planetary Protection Implementation Document” will cover the procedures and specific details on how the Planetary Protection requirements will be met. This document will include analyses supporting entry heating, orbital lifetime, and launch recontamination, bioburden allocation and reduction, and the microbiological assay procedures. This document will also include detailed lists of exposed surfaces, cleaning schedule, sampling, and last access, and burden allocation.

### **9.2 PRE-LAUNCH REPORT**

The “ARES Planetary Protection Pre-Launch Report” will be a report to the NASA PPO which will present, prior to launch, bioassay results, the estimated total exposed surface bioburden as well as analyses results demonstrating probabilities of impact for all encountered celestial bodies by all launched hardware are within required limits.

### **9.3 POST-LAUNCH REPORT**

The “ARES Planetary Protection Post-Launch Report” will be a supplemental report (to the Pre-Launch Report) to the NASA PPO from the Project. This report will summarize and update the Pre-Launch Report to include final burden results (if changes occur) and to document launch and early post-launch events for the mission.

### **9.4 END-OF-MISSION REPORT**

The “ARES Planetary Protection End-of-Mission Report” will be a supplemental report (to the Pre-Launch Report) to the NASA PPO from the Project. This will be the final report which will document the actual compliance of the ARES Project with the planetary protection requirements.

## 9.5 DOCUMENTATION SCHEDULE

The schedule shown in the Table 12 indicates planetary protection documentation publication dates and the dates when approval by the NASA Planetary Protection Officer is required.

**Table 12. Planetary Protection Document Schedule**

Plan/Report	Review	Description	Submitted to NASA PPO
Project Planetary Protection Plan (PPPP)	Project Planetary Protection Review	Provides the detailed planetary protection compliance approach and implementation requirements. Also includes required PP Subsidiary Plans.	30 days prior to ARES Project PDR
Planetary Protection Implementation Document	N/A	Covers the procedures and specific details on how the Planetary Protection requirements will be met	ARES Project PDR
Pre-Launch Planetary Protection Report	Pre-Launch Planetary Protection Review & Launch Readiness Review	Documents the project compliance with PP requirements. Report includes the organic material inventory.	90 days prior to launch or as noted in the approved PPPP
Post-Launch Planetary Protection Report	N/A	Updates the Pre-Launch Planetary Protection Report.	60 days after launch or as noted in the approved PPPP.
End of Mission Report	N/A	Provides a complete report of PP requirement compliance and the final actual disposition of launched hardware.	30 days after the formally declared "end of mission" or as noted in the approved PPPP.
Inventory of Bulk Organic Constituents	N/A	Contains data relevant to organic material identification of the CS, entry system, and AFS; the locations of landings and impact points of the entry system and the AFS on the surface of Mars, and; estimates of the condition of the entry system and AFS after landing to assist in determining the spread of organic materials.	Included with the End of Mission Report.

# 10.0 REVIEWS

The ARES Project will conduct periodic formal and informal Planetary Protection reviews to provide the PPO with detailed planetary protection compliance data and ensure all requirements will be met prior to launch.

## 10.1 PROJECT PLANETARY PROTECTION REVIEW

A Project Planetary Protection Review is optional, at either the project or NASA PPO request. The purpose of this review is to enable the necessary communication for the formal version of the Planetary Protection Plan to be approved without major change or delay. Note that this review would be held in conjunction with the Project Preliminary Design Review, subject to the approval of the PPO. This review would be included in the project schedule.

## 10.2 PLANETARY PROTECTION COMPLIANCE STATUS REVIEWS

Planetary Protection Compliance Status Reviews will be conducted to address the degree of implementation planning and preparation completed in order to follow through with the plans in the Planetary Protection Implementation document, previously approved. Each review shall address the status of the compliance with Planetary Protection requirements at the time of the review. All events that affected the degree of compliance will be reviewed. These formal reviews will be held within 2 weeks before or after the ATLO Readiness Review and the Spacecraft (full spacecraft consists of CS, entry system, and AFS) Delivery (Pre-Ship) Review, or per the approved PP Plan.

## 10.3 PRE-LAUNCH PLANETARY PROTECTION REVIEW

A Pre-Launch Planetary Protection Review will be conducted to ascertain that the Project has to date, met its Planetary Protection requirements, to examine in detail the planetary protection activities accomplished prior to the review, and to review the remaining activities up to launch. The Pre-Launch Planetary Protection Report, approved by the Project, shall form the framework for this review. This review would be held between 120 and 90 days before launch or per the approved Planetary Protection Plan. The NASA PPO shall participate in the ARES project’s formal Launch Readiness Review. Any event that occurred after the Planetary Protection Pre-Launch Review and before the Launch

Table 13. Formal Planetary Protection Review Schedule

Planetary Protection Review	Scheduling Rationale
Compliance Status	2 weeks prior to ATLO Readiness Review
Compliance Status	2 weeks prior to Spacecraft Delivery (Pre-Ship) Review
Prelaunch PP Readiness Review	90-120 days before launch

## **11.0 FACILITIES AND SERVICES**

### **11.1 ARES MICROBIOLOGY LABORATORY (JPL)**

JPL shall establish a microbiology laboratory or contract a suitable facility. The laboratory shall be staffed and equipped appropriately, by JPL or under a contract to JPL, to perform the required Project bioassays conducted at JPL.

### **11.2 ARES MICROBIOLOGY LABORATORY (LaRC)**

LaRC shall establish a microbiology laboratory or contract a suitable facility. The laboratory shall be staffed and equipped appropriately, by LaRC or under a contract to LaRC, to perform the required Project bioassays conducted at LaRC.

### **11.3 ARES MICROBIOLOGY LABORATORY (KSC)**

A microbiological laboratory shall be provided at KSC to perform pre-launch bioassays. This support will be arranged via the ARES Project Launch Site Support Plan and other KSC documents, as required.

All facilities, equipment, and materials necessary to perform the required sampling and bioassay activities shall be provided by the NASA PPO. The NASA PPO shall be responsible to ensure that all equipment at the KSC laboratory is properly maintained.

JPL will be responsible for providing some personnel to support the bioassay activities at KSC. The NASA PPO will provide the personnel and facilities for the final verification assays.

### **11.4 GOVERNMENT SERVICES**

Contamination control measurements in the payload and propulsion handling facility (PHSF) will be required. This support will be arranged via the ARES Project Launch Site Support Plan.

## 12.0 ACKNOWLEDGEMENTS

The author would like to acknowledge and thank Henry S. Wright, Chief Engineer for ARES, NASA Langley Research Center, and Barbara Larsen and Jordan Evans, NASA Jet Propulsion Laboratory, for their contributions to the ARES planetary protection activities and to the development of the ARES Planetary Protection Strategy.

## 13.0 REFERENCES

1. NASA Policy Directive, NPD 8020.7F “Biological Contamination Control for Outbound and Inbound Planetary Spacecraft”, Washington DC, February 19, 1999 (Revalidated October 23, 2003).
2. NASA Procedural Requirements, NPR 8020.12C “Planetary Protection Provisions for Robotic Extraterrestrial Mission”, Washington DC, April 27, 2005.
3. NASA Mars Scout Proposal Number 06-Scout06-0003, “Aerial Regional-scale Environmental Survey (ARES) for Mars,” July 31, 2006.
4. “Findings of the Mars Special Regions Science Analysis Group,” ASTROBIOLOGY Volume 6, Number 5. 2006.
5. “Delta II – Payload Planners Guide”, MDC 00H0016, The Boeing Company, October 2000.
6. “Mars Exploration Rover (MER) Project Planetary Protection Plan,” NASA/JPL Project Document Number MER420-1-109, November 2000.
7. NASA Handbook NHB 5340.1B, “Standard Procedures for the Microbiological Examination of Space Hardware,” Washington DC, 1980.

## 14.0 LIST OF ACRONYMS

AES	AFS Extraction System
AFS	Atmospheric Flight System
AGL	Above Ground Level
ARES	Aerial Regional-scale Environmental Survey
ATLO	Assembly, Test and Launch Operations
C&DH	Command & Data Handling
CCAFS	Cape Canaveral Air Force Station
CS	Carrier Spacecraft
DHMR	Dry Heat Microbial Reduction
EDD	Entry, Descent, and Deployment
EDL	entry, descent, and landing
FSW	Flight Software
JPL	Jet Propulsion Laboratory
KSC	Kennedy Space Center
LaRC	NASA Langley Research center
LV	Lunch Vehicle
MAG	Magnetometer
MER	Mars Exploration Rover
MGS	Mars Global Surveyor
MIMU	Miniature Inertial Measuring Unit
MMH	Monomethyl Hydrazine (Fuel)
MON-3	Mixed Oxides of Nitrogen (oxidizer)
MPF	Mars Pathfinder
MRO	Mars Reconnaissance Orbiter
MS	Mass Spectrometer
MSAP	Multi-Mission System Architectural Platform
PPO	Planetary Protection Officer
NPG	NASA Procedures and Guidelines
NPR	NASA Procedural Requirements
NS	Neutron Spectrometer
PIU	Pyro Initiation Unit
PP	Planetary Protection
PPM	Planetary Protection Manager
STA	Science Target Area
TCM	trajectory correction maneuver
TPS	thermal protection system
UHF	Ultra High Frequency



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